Application of the Liquid Coil as an Embolic Material for Arteriovenous Malformations

A. KURATA, S. SUZUKI, H. OZAWA, I. YUZAWA, M. YAMDA, K. FUJII, S. KAN, T. KITAHARA, T. OHMOMO*, Y. MIYASAKA**

Departments of Neurosurgery, Radiology and Critical Care Medicine, Kitasato University School of Medicine; Kanagawa
**Department of Neurosurgery, Chouf Hospital; Tokyo*
***Department of Neurosurgery, Yamato Municipal Hospital. Kanagawa; Japan*

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Summary

The purpose of this paper is to clarify advantages and disadvantages of platinum liquid coils as an embolic material for AVMs. During the last eight years, 50 endovascular procedures using liquid coils were conducted in our institute for 19 cases with AVMs, 15 of which were located in the eloquent area. All but one presented with haemorrhage, the exception demonstrating repeated ischemic symptoms. Only liquid coils were used as the embolic material to obliterate the nidus and feeders. In ten of the 15 patients with AVMs located in the eloquent area and one case rejecting surgery, liquid coil embolization was applied one to 11 times (average 3.5 times) to achieve decrease in size and this was then followed by radiosurgery. The remaining eight AVM patients underwent total removal after liquid coil embolization. No complications were encountered during the peri-embolization period. In all cases, the purpose of embolization was to diminish the size to facilitate radiosurgery and decrease bleeding during surgery.

The liquid coil has advantages as a material for embolization of AVMs; it is non-toxic and bioinart material; it seldom occludes normal minute vascular channels; when it used in a nidus, it seldom to migrates in the venous direction, and it has good radio-opacity and offers good marking for surgery. Appropriate applications include preoperative embolization or pre-radiosurgical embolization of AVMs, especially when staged embolizations are performed to reduce risk of perfusion pressure breakthrough in patients which are large or located in the eloquent area.

Introduction

various kinds of embolic materials have been used for the treatment of AVMs and particularly to diminish the size of the nidus and arterial inflow into the nidus for pre-surgery and pre-radiosurgery.

In some cases, endovascular surgery using liquid material can establish complete obliteration of the nidus, especially in simple and relative small AVMs with few feeders. Of the available liquid materials, N-butyl-2-cyanoacrylate (NBCA) has been widely used as an mbolic material [1-5] in place of isobutyl 2-cyanoacrylate (IBCA), with many applications. However, for some AVMs located in the eloquent area or with large size having a risk of perfusion pressure breakthrough, liquid material may be unsuitable for use and non-liquid materials may be more appropriate.

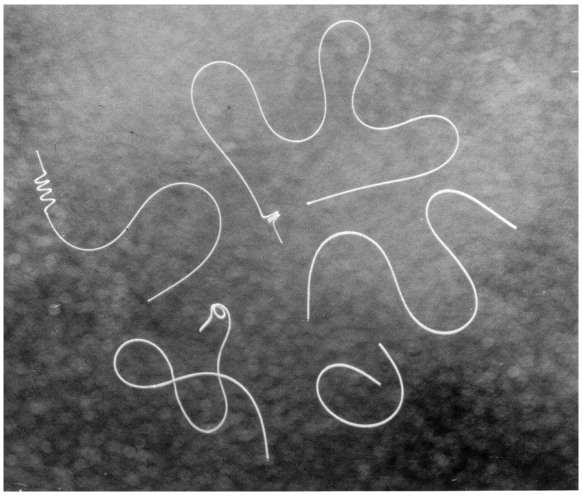


Figure 1 The various types of liquid coil manufactured from platinum alloy are illustrated at the top. Both helical and straight forms, each available in 10 and 18 types of microcatheters, are produced. The helical diameter is only 2.5 mm. The platinum core wire diameter of the10 type is 0.001 inch with a primary coil diameter of 0.008 inch. The platinum core wire diameter of the 18 type is also 0.001 inch while the primary coil diameter is 0.016 inch. The straight type is available in 2 cm, 5 cm, 10 cm, 20 cm or 30 cm lengths, and the helical type, in 1.5 cm, 2.2 cm, 5.0 cm, 10.0 cm and 30.0 cm units. The liquid coil injection set-up is shown at the bottom of figure 1. The sheath including the liquid coil is inserted into a rotating haemostatic valve, and the liquid coil can thus be easily injected through the microcatheter system.

Approximately ten years before, platinum liquid coils have developed by Berenstein A and became commercially available (Boston Scientific, Co. Los Angeles, California). Their unique characteristics include an ability to float in the blood stream to reach the target region. However, reports of use of such liquid coils for large series of patients have hitherto been lacking. Therefore, to clarify the advantages and disadvantages for AVM embolization, the present research was conducted with two types of liquid coils, straight and helical (figure 1) with two primary coil diameters, 0.008 inch for use with a 10 type microcatheter and 0.016 inch for 18 type microcatheters.

Patients and Methods

Between March 1996 and July 2004, 50 endovascular procedures using liquid coils were conducted for 19 cases of AVMs, 15 of which were located in the eloquent area (table 1). The patient ages ranged from 11 to 68 years (mean: 40) and all except three were males. Intracerebral haemorrhage was the most common reason for initial presentation, occurring in 18 of the nineteen cases. Altogether, these patients experienced 31 haemorrhages (average, 1.8 haemorrhages /patient; range [1-9]).

One patient (Case 10) presented with repeated ischemic symptoms (transient hemiparesis). In all cases, isosorbide dinitrate (Frandol tape) was applied to the chest to prevent vasospasms 15 minutes before the endovascular surgery, and transfemoral approaches were selected using a 6F sheath and a 6F introducing catheter. Tracker-18, Spinaker (Boston Scientific, Co, California), Microferret (William Cook Europe, Co, Denmark) or Magic Catheters (Balt Extrusion, France) were used as microcatheters. In all cases, endovascular surgery was performed under local anesthesia with EEG or and ABR monitoring.

Control ACT (activated clotting time) was initially measured with 2 ml of blood sampled via the femoral sheath and thereafter 2000U heparin was injected. During the endovascular surgery, continuous heparinization (3000U heparin in 500 ml physiological saline solution) was maintained through the sheath, introducing catheter, and microcather to maintain an appropriate ACT between two and three times the control value. A total of 6000-7000U heparin was usually used for each endovascular operation.

In all cases, liquid coils were employed as the sole embolic materials to obliterate the nidus and feeders in the eloquent area. In the majority of cases, 2 cm straight type coils or 2.2 cm herical type coils were used. In all eleven cases, the purpose of the endovascular surgery was to achieve a decrease in size sufficient to allow application of stereotactic radiosurgery (SRS). The details are given below. With the other eight cases, the purpose of endovascular surgery was to diminish the risk of complications and bleeding at surgical removal. Generally, deep-seated parts of AVMs were embolized using liquid coils before surgery.

Representative Cases

Case 9

When the male patient was 27-year-old, a pontine haemorrhage developed, resulting in right hemiparesis, left cranial V to VIII palsies and cerebellar ataxia. A second episode of rebeeding occurred at 46 years of age, which was

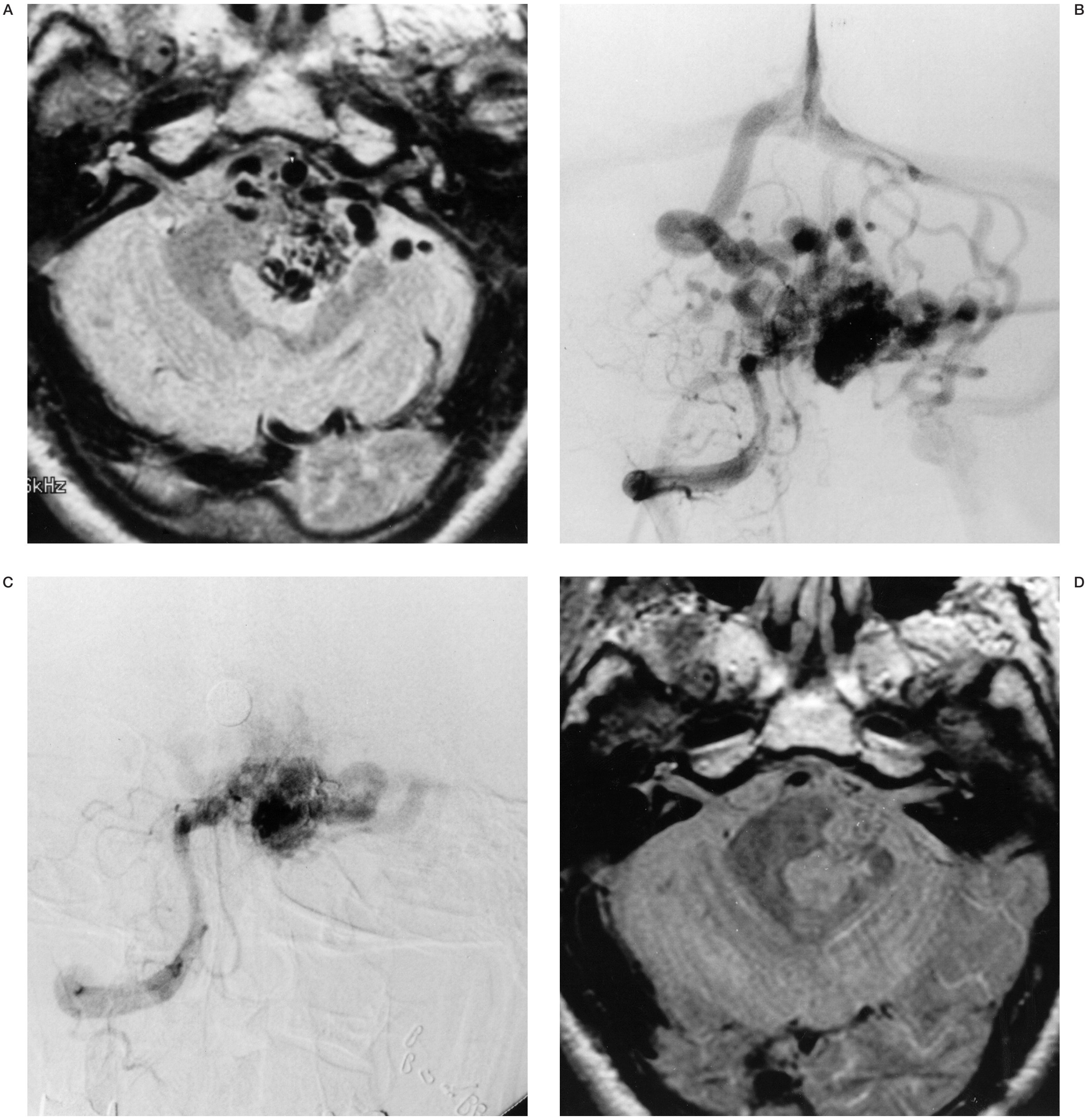


Figure 2 (case 9) A) The AVM is located on the left side of pons and cerebellar peduncle. B) A left vertebral artery angiogram showing the AVM mainly fed by branches from left anterior inferior cerebellar artery (AICA) C) Left vertebral angiogram after three repeated embolizations for AICA division using liquid coils (10 type, straight 2 cm x 27) D) MRI at 20 months after radiosurgery, showing disappearance of the AVM.

mainly in the fourth ventriculum originating from the pons. Neurological examination on admission revealed only slight aggravation of neurological symtoms. The AVM was located on the left side of pons and cerebellar peduncle (figure 2A) and mainly fed by branches from the left anterior inferior cerebellar artery (AICA) (figure 2B). Three repeated embolizations for AICA diversion using liquid coils (10 type straight 2 cm x 27) were successfully performed (figure 2C). One month later, stereotactic radiosurgery (SRS) was conducted (center

Table 1 **Summary of AVM patients treated with liquid coil embolization.**

Cases No	Age/ Sex	Clinical-symptom (times)	AVM grade*	location	No. of. emb proced.	OS** or SRS*** (times)	Re-bleeding	Oblite-ration (month)	GOS (time)
1	29F	haemorr-hage (9)	V	rt-basal ganglia	11	SRS(2)	+	I (2M)	VS (57M)
2	47M	haemorr-hage	III	rt temporo occipital	1	OS	none	C (1M)	GR (101M)
3	24F	haemorr-hage	IV	lt frontal	2	OS	none	C (1M)	GR (93M)
4	68M	haemorr-hage	II	lt parito-occipital	1	OS	none	C (1M)	GR (101M)
5	26M	haemorr-hage (4)	V	rt-basal ganglia	5	SRS	none	I (25M)	MD (25M)
6	51M	haemorr-hage (2)	III	corpus-callosum	1	SRS	none	C (44M)	GR (66M)
7	33M	haemorr-hage	III	brainstem	1	SRS	none	C (9M)	MD (7M)
8	60M	haemorr-hage	II	rt-temporal	4	SRS	none	I (14M)	GR (14M)
9	46M	haemorr-hage	IV	brainstem	4	SRS	+	C (34M)	MD (36M)
10	32M	steal-phe-nomenon	III	lt-frontal motor cortex	1	SRS	unde-termined		
11	43M	haemorr-hage	IV	lt-fronto parietal	1	OS	none	C (1M)	GR (72M)
12	39M	haemorr-hage	II	rt-parietal	1	OS	none	C (3M)	GR (29M)
13	43M	haemorr-hage	III	lt-parietal	1	OS	none	C (1W)	GR (30M)
14	61M	haemorr-hage	IV	rt-fronto-temporoparietal	10	SRS	none	I (26M)	GR (26M)
15	11F	haemorr-hage	IV	rt caudate head	1	SRS	none	C (30M)	GR (34M)
16	21M	haemorr-hage	III	lt-parieto occipital	1	OS	none	C (1W)	GR (17M)
17	47M	haemorr-hage	III	brainstem cerebellum	1	SRS	none	I (6M)	GR (12M)
18	27M	haemorr-hage	IV	lt-frontal	2	SRS	none	I (9M)	MD (10M)
19	53M	haemorr-hage	II	rt-temporal	1	OS	none	C (1W)	GR (6M)

AVM: arteriovenous malformation, AVM grade by Spetzler & Martin*[21]
OS: open surgery, SRS: stereotactic radio-surgery, I: incomplete, C: complete,
GOS: Glasgow Outcome Scale; GR: good recovery, MD: moderately disabled, SD: severely disabled,
VS: vegetative survival

dose 36 Gy, marginal dose 18 Gy). A third attack of haemorrhage occurred at 18 months after the radiosurgery but this was mild and did not aggravate the neurological symptoms. Angiography showed remarkable decrease of the nidus following further embolization using a 10 type straight coil for the residual branch from the left superior cerebellar artery. One year and eight months after the radiosurgery, MRI showed disappearance of the AVM (figure 2D). Follow-up MRI and MRA two years and three years after radiosurgery also showed no residual nidus.

The clinical course was also uneventful and it has now been three years and three months since the last attack.

Case 12

The patient was a 39-year-old man, who was followed conservatively with anticoagulant medication subsequent to a right frontal infarction caused by a superior sagittal sinus thrombosis. After two years he was admitted to our hospital with abnormal computed tomography (CT) and MRI findings. Neurological examination on admission revealed no abnormalities. Right carotid angiograms revealed a AVM located in the parietal lobe fed by the posterior parietal artery and the callosomarginal artery. The posterior parietal artery was catheterized superselectively with a Tracker 10 catheter, and intranidul embolization was successfully carried out using liquid coils (10 type straight 2 cm x 4). Direct surgery to resect the nidus was performed 17 days after coil embolization, when the liquid coils were recognized in the nidus (figure 3A). Histological findings showed obliteration with no foreign body giant cell reaction (figure 3B).

A

B

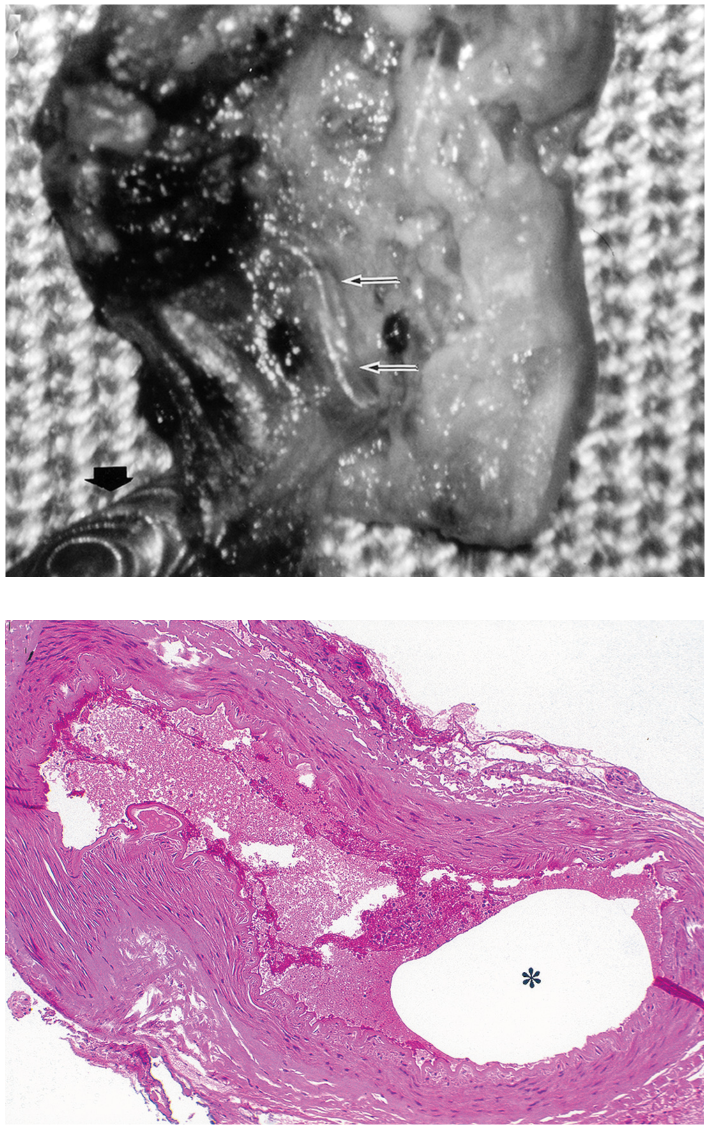


Figure 3 (case 12) A) Macroscopic view showing multiple vascular channels and parts of the nidus (small arrows) and feeding arteries obstructed with liquid coils (large arrow). B) Histopathological findings for an AVM obstructed with liquid coils (*). Note the minimal foreign body giant cell reaction.

Case 15

An 11-year-old female presented with a generalized seizure. Computed tomography on admission showed intraventricular haemorrhage and angiograms revealed an AVM, mainly located in the caudate head, fed by the right Heubner artery and draining into the internal cerebral vein via the thalamostriate vein (figure 4A). SRS was selected because of the location in the eloquent area. The size of the AVM was over 3 cm and to decrease the flow and size embolization using a liquid coil was conducted (figure 4B). SRS (center dose: 24 Gy, marginal dose: 20 Gy) was undergone four days after the embolization. The clinical course was uneventful and follow-up angiography 2.5 years thereafter showed disappearance of the AVM (figure 4C).

Results

In all our cases, liquid coil embolization to obliterate the nidus and feeder in eloquent areas could be successfully performed without complications (table 1). This was also true for two huge inoperable AVMs (cases 1 and 5) and brainstem AVMs (cases 7, 9 and 17) with repeated applications. A total of 50 procedures were performed (average, 2.6 procedures/ patient). In cases 1, 3, 5, 8, 9 and 14, a second embolization performed between seven days and 14 days after the first, resulted in no recanaliztion. In eleven cases, radiosurgery could then be carried out due to the achieved decrease in size. In the other eight, diminished bleeding during surgery and easy resection of a deep seated nidus allowed total removal without complications.

The angiographic follow up period after final treatment (microsurgery, endovascular surgery or radiosurgery) ranged from one week to 44 months (average, 13 months). The AVMs were completely eliminated in all eight patients treated with microsurgical resection and four patients treated with radiosurgery; six patients had residual AVMs. The other one (case 10) was lost to follow-up. In one patient (case 1) with a residual AVM, rebleeding occurred two years after the radiosurgery. After the rebleeding, two further embolizations were added, but rebleeding occurred one month after eleven embolizations, resulted in a vegetative state. In the other five patients with residual AVMs, the period after final treatment ranged from 1 to 26 months (average, 15.5 months). Complete obliteration of their AVMs is expected within the latency period.

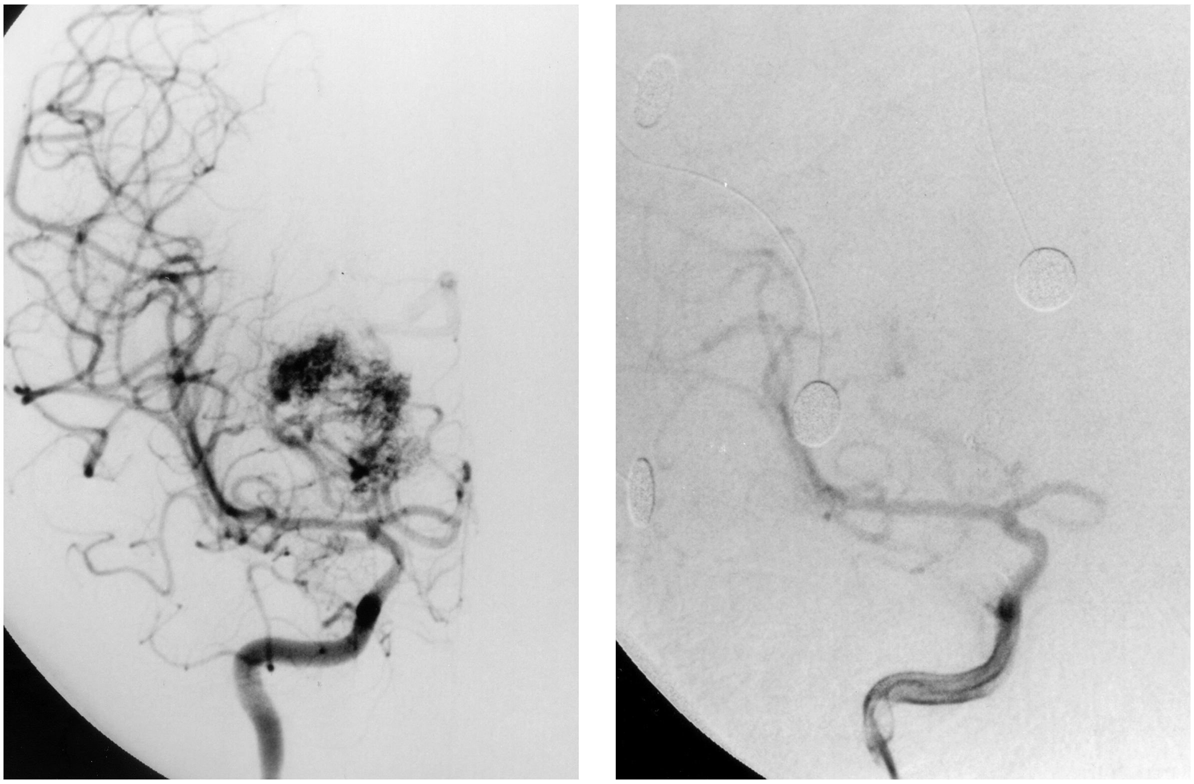
Discussion

This first report of application of liquid coils for embolization of AVMs in a comparatively large series demonstrated many advantages as embolic materials. For AVMs, n-butyl-2-cyanoaclylate (NBCA) is now widely used [1-5] instead of isobutyl 2-cyanoaclylate (IBCA), since it is effective for obliteration of the nidus and vessels embolized with NBCA are compressible and easily cut with microscissors, without increasing surgical complications or morbidity rates [3]. However, especial attention needs to be paid to adhesion of the catheter to vessels and not to migrate into the venous side, which may produce haemorrhage. Jafar et Al [3] reported four (20%) of 20 large AVM patients to suffer post-embolization complications with NBCA. On the other hand, Debrun et Al [1] described minor neurological deficits in only 2 (4%) of 54 AVMs, but two deaths (4%) occurred and catheter fragments persisted in 6 (11%), resulting in adherent catheter tips. Recently, Yu et Al [5] reported the utility of cyanoacrylate. With six small AVMs (the nidus: not larger than 3 cm) having few feeders (the number: not exceeding 3), complete obliteration could be achieved without complications. They reported also an overall cure rate of AVMs with cyanoacrylate embolization of 22% (6 of 27).

Non-adhesive and easy resectable liquid materials has been a focus for development research and Taki et Al [6] reported ethylene vinyl alcohol copolymer (EVAL) as a new example. Yamashita et Al [7] determined physical characteristics and showed the various EVAL mixtures are suited to embolizing different types of AVM but unfortunately an experimental study revealed the dimethyl sulfoxide (DMSO) used as a solvent to be angiotoxic so that infusion may causes immediate, moderate to severe vasospasm and results in either subarachnoid haemorrhage or strokes due to the transmural necrosis with extravasation seen in the subacute and chronic stages [8]. Recently, an EVAL/ ethanol mixture instead of DMSO has been introduced [9,10], histopathological examination of a number of cases disclosing only mild inflammation within the embolized lumen without inflammatoly reactions in the media or adventitia. The authors concluded that the material is easy to handle and is an effective and safe embolic agent for preoperative embolization, so that the EVAL/ethanol mixture may be close to ideal as an embolic material for non-eloquent AVMs. Another commonly applied embolic material is PVA [11], which may be used as particles with microfibrillary collagen (Aviten) and 30% ethyl alcohol [12,13]. The reported advantages are the ability to embolize the nidus for a comparative long period [12-14], easy injection through microcatheters and simple resection [15]. One major disadvantage is that it is not visible under X rays.

Deveikis et Al [16] reported that the disadvantages outweigh the advantages of silk as an embolic agent because silk sutures can cause delayed haemorrhage between two and seven days after the initial silk embolization, resulting

A B



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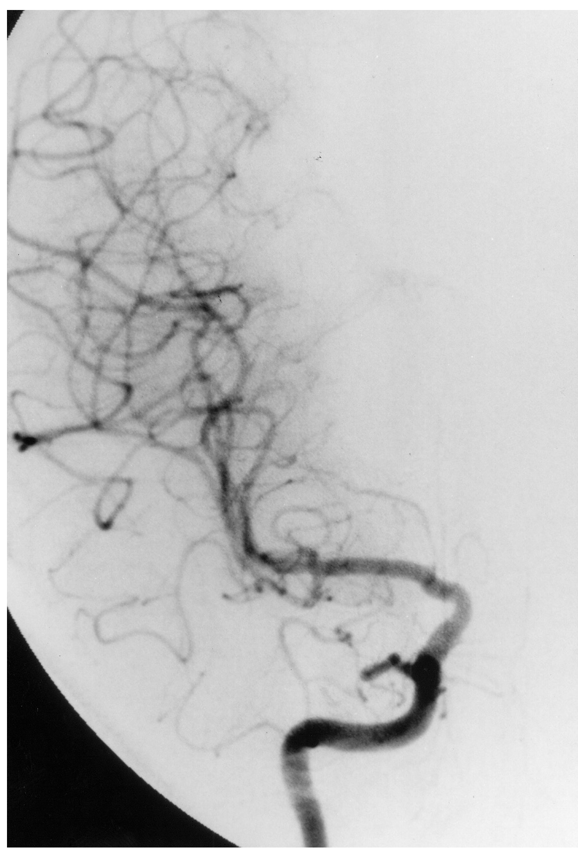

Figure 4 (case 15) A) Right internal carotid angiogram showing an AVM mainly located in the caudate head, fed by the right Heubner artery and draining into the internal cerebral vein via the thalmostriate vein. B) Right internal angiogram after liquid coil embolization. C) Follow-up angiogram 2.5 years after the stereotactic radiosurgery showing disappearance of the AVM.

in fulminate vasculitis. On the other hand, Song et Al [17] reported silk sutures to be an effective and relatively safe embolic agent for preoperative embolization of AVMs. They stressed that delayed haemorrhage due to local inflammation after silk suture embolization is not a significant problem in preoperative patients because transmural inflammation or necrosis did not prove to be a histological feature of resected specimens. However, the disadvantages include radiolucency and the lack of permanent embolization.

Another embolic material, polylene threads, was reported by Benati et Al [18,19] to allow 50% or more of the nidus to be obliterated in nine of eleven AVMs. They concluded that this nontoxic and biocompatible material can be used as a preoperative embolic agent [18], but in a large series, the overall complication rate was 19.5%

(21/108) and the average reduction of the nidus was only 37%. A further disadvantage is the lack of radio-opacity. Silk suture and polylene threads can allow staged embolizations, reducing the risk of perfusion pressure breakthrough in patients with large AVMs, but the difficulty with visualization means that direct comparison with platinum liquid coils is possible. NBCA, EVAL/ethanol mixture and PVA particles can quickly occlude the nidus of an AVM but can also penetrate into small functional branches originating from the same feeder which are not evident if an arterial steal is present. Liquid coils as an embolic material for the embolization of AVMs have the advantage of not migrating to such functional small branches. They are also radiopaque and nontoxic, not eliciting any obvious foreign body giant cell reactions.

Halbach et Al [20] have reported the efficacy of preoperative balloon occlusion for AVMs. They emphasized the decrease of bleeding and easy removal of AVMs that could be achieved with low complication rates. However, liquid coil embolization is a more effective preoperative procedure because distal embolization can also be accomplished. With balloons, only proximal occlusion of the feeding arteries is possible. Application of liquid coils is more appropriate for the embolization of AVMs located in the eloquent area, as evidenced by the present series where no complications were encountered.

Yang et Al [21] first reported the efficacy of platinum wire for the embolization of AV fistulas, complete occlusion being obtained in six of nine cases without permanent neurological deficits. However, they emphasized the poor thrombogenicity and the difficulty of achieving dense and compact packing into a fistula. In our experience also, loose packing of the liquid coils never produced complete occlusion of larger vessels. In such cases, follow-up angiograms should be performed and appropriate further measures then undertaken. The poor thrombogenicity is due to the non-toxic nature of platinum as a material. The liquid coil has other disadvantages. For navigation, pressure injection is indispensable, which may damage or destroy the fragile vessels and dislocation of the tip of the catheter can result in migration of the liquid coil. Gentle injections should be performed. Also to confirm the fixation of the tip of the catheter, test injection of the contrast medium should be carried out before liquid coil embolization, especially when using floppy catheters.

Conclusions

In conclusion, with the present series of repeated embolizations for 19 AVMs, 15 in the eloquent area, no complications were encountered during the peri-embolization period. In all eleven non-surgical AVMs, reduction of the size and flow could be attained, facilitating stereotactic radiosurgery. In all eight operative AVM patients, liquid coils proved to be good markers for resection.

Lawton et Al [22] recommended multimodality treatment for deep AVMs. The central issue in designing a treatment for AVMs is surgical accessibility with or without endovascular surgery for devascularization. In contrast surgically inaccessible cases, endovascular surgery will be needed to reduce size and allow radiosurgey. The goal in each case is complete elimination of the AVM with preservation of the neurological function of the patient. Endovascular surgery should be performed with this in mind.

The liquid coil has advantages as an embolic material for embolization of AVMs: no migration to normal minute vascular channels; radio-opacity; good marking for surgery. Overall, the present results indicate that liquid coils may be considered as a prime candidate for preoperative or pre-radiosurgical embolization of AVMs, especially when staged embolizations are performed to reduce the risk of perfusion pressure breakthrough in patients with AVMs which are large or located in the eloquent area.

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A. Kurata, M.D.
Department of Neurosurgery, Kitasato University School of Medicine
1-15-1, Kitasato, Sagamihara, Kanagawa, Japan
E-mail: akirak@med.kitasato-u.ac.jp